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Italiadomani
PIANO NAZIONALE DI RIPRESA E RESILIENZA

ICSC
Centro Nazionale di Ricerca in HPC, Big Data and Quantum Computing

Assessing the relevance of systematics in the LiteBIRD experiment

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Spoke 3 General Meeting, Elba 5-9 / 05, 2024

Scientific Rationale

LiteBIRD -**L**ite (Light) satellite for the studies of **B**-mode polarization and **I**nflation from cosmic background **R**adiation **D**etection- **Experiment**→ measure CMB angular power spectrum in seek of B-modes

CMB anisotropies → Inflation Hypothesis

Inflation→ Primordial gravitational waves→ Tensor Perturbations→B-mode polarization

Polarization anisotropies (Linear polarization)

→ **E-modes** (symmetric under parity transformation w.r.t. the propagation direction)

→ **B-modes** (antisymmetric under parity transformation w.r.t. the propagation direction)

Progress of Theoretical and Experimental Physics, Volume 2023, Issue 4, April 2023, 042F01, https://doi.org/10.1093/ptep/ptac150

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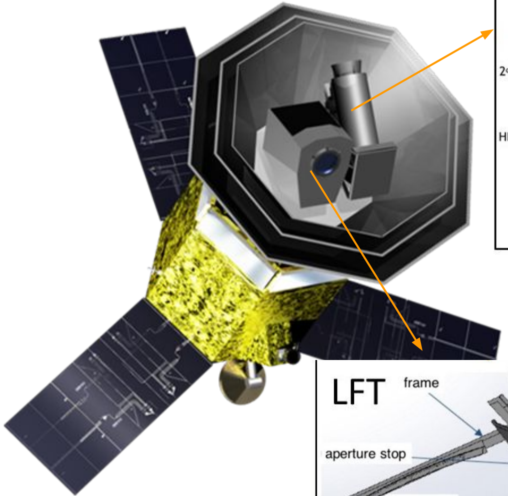
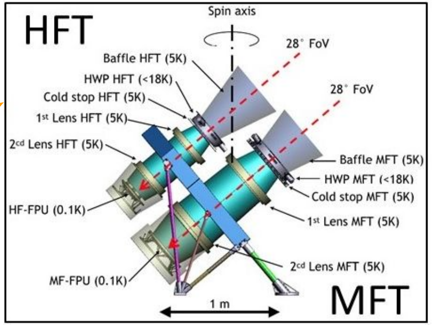
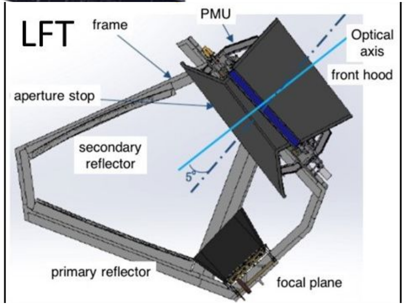
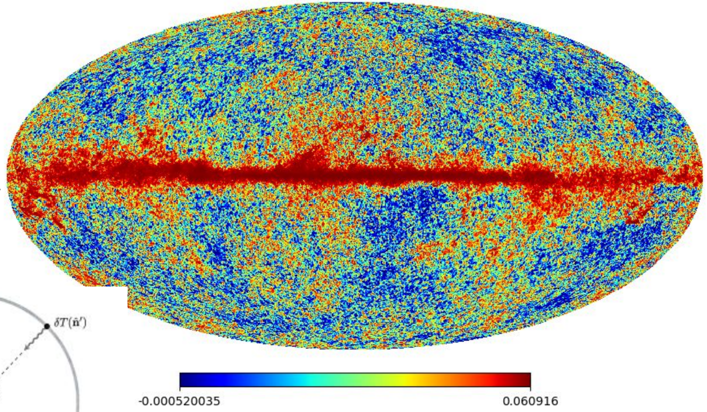
Scientific Rationale

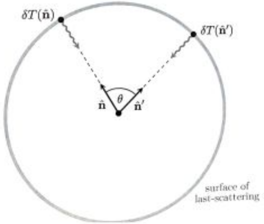






Planck map

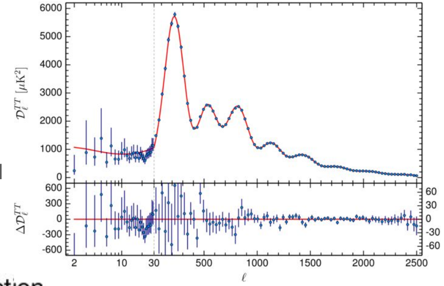




from Baumann, Cosmology

$$\Theta(\hat{n}) = \frac{T(\hat{n}) - T_0}{T_0}$$

Expansion in spherical harmonic



Build the average of the 2-point correlation function
$C(\theta) = < \Theta(\hat{n})\Theta(\hat{n}') >$

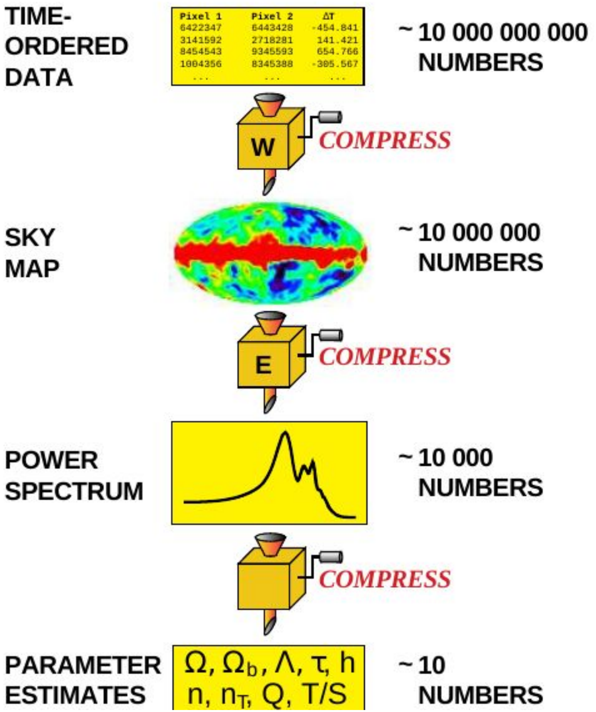
Technical Objectives, Methodologies and Solutions

-Objective: Recover parameters from Time Ordered Data (TOD)

The analysis pipeline has the objective to compress a large amount of data to extract few parameters.

This is an expensive process→ simulations with mocked data will help us in preparation of the actual data.

- Addressing the role of systematic effects is crucial in order to define a complete analysis pipeline.



Max Tegmark and Angelica de Oliveira-Costa
Phys. Rev. D 64, 063001 – Published 16 August 2001

Technical Objectives, Methodologies and Solutions

How to simulate the analysis pipeline? → LiteBIRD Simulation Framework

LiteBIRD simulation pipeline

Navigation

Contents:

Welcome to litebird_sim's documentation!

Contents:

The LiteBIRD simulation framework is a Python package that can simulate the data acquisition process for the three instruments that will be present onboard of the LiteBIRD Spacecraft.

↓

TOD Generation and analysis

↓

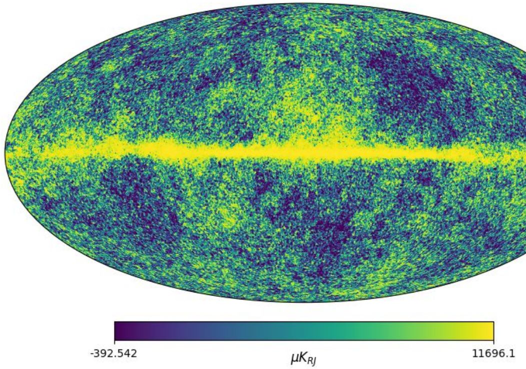
Some systematics, such as crosstalk, need to be added to the framework

https://litebird-sim.readthedocs.io/en/latest/index.html#

Technical Objectives, Methodologies and Solutions

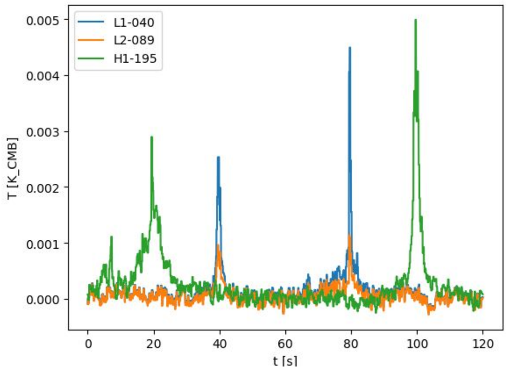
- **TOD is a time series of data points, indexed and in time order**. → LiteBIRD will sample the sky with a frequency ~19 Hz.
- In the actual experiment raw TOD will be used to build a sky map.
- In the Simulation Framework we proceed in the opposite direction

From an injected map



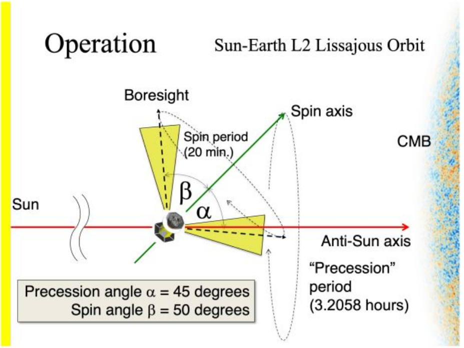
+ Impose a scanning strategy

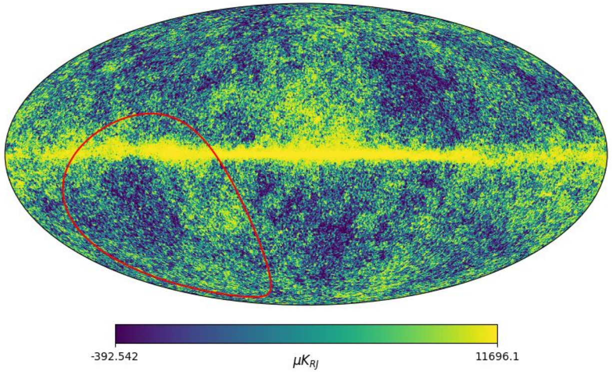
to TOD (numpy arrays)



Technical Objectives, Methodologies and Solutions

Scanning strategy





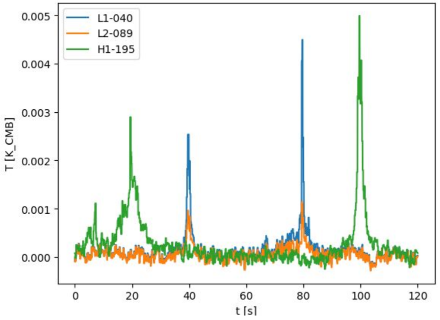
TOD vector

Pointing Matrix (Nsample x 3Npixel)

noise vector

$$d_t = \sum_p A_{tp} m_p + n_t$$

input Sky map



Technical Objectives, Methodologies and Solutions

Once the TOD are generated (comprehensive of noise) we shall recover the sky map by "Inverting" the TOD equation .

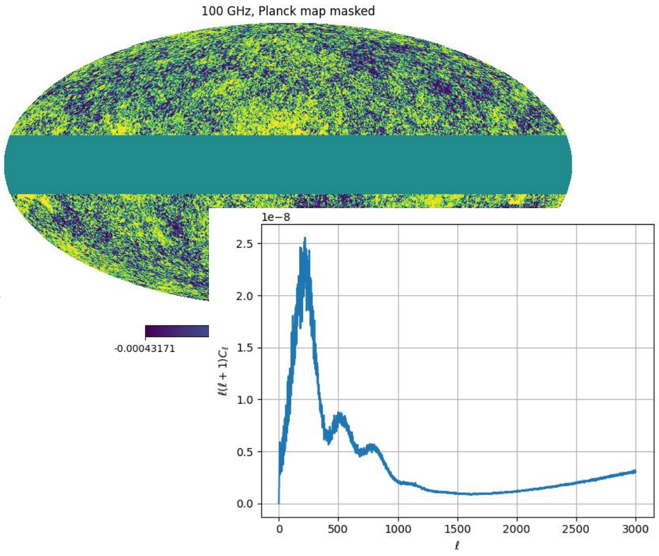
If only white noise

$$\hat{m} = \left(A^T C_w^{-1} A\right) A^T C_w^{-1} d$$

with

$$C_w^{-1} = \begin{pmatrix} \frac{1}{\sigma^2} & 0 & 0 & \cdots \\ 0 & \frac{1}{\sigma^2} & 0 & \cdots \\ 0 & 0 & \frac{1}{\sigma^2} & \\ \vdots & \vdots & & \ddots \end{pmatrix}$$

Finally recover the power spectrum from the reconstructed map (healpy library)



Technical Objectives, Methodologies and Solutions

Crosstalk → Different detectors mutually interact with each others
Crosstalk across different frequency channels will mix different amount of foreground components
→ **biased results**

Crosstalk will mix the TOD according to →

$$\tilde{d}^i = \sum_j X^{ij} d^j$$

Large number of detectors (~5000) and large number of time samples (~10^9)
→ Big Data and parallelization problem

Experimentalists can reduce the crosstalk in the design, **our objective** is to address the amount of bias injected into the signal from a given crosstalk matrix.

Our Final Task is to perform simulations with different crosstalk matrices in order to study their impact on the final results.

Timescale, Milestones and KPIs

Milestone 7-8

- Study the literature
- Understand the problem
- Develop a scientific project

Milestone 9 (June 2024-October 2024)

- **Study the crosstalk and how to implement it**
- **Debug**

→ **KPIs**: simulation reports

Milestone 10 (-August 2025 ?)

- **Optimization**
- **Final Simulations**
- **Study the results**
- **Write a Paper**
- **Release on Github**

→ **KPIs**: Simulation reports, draft of the paper and/or github package

Accomplished Work, Results

- **Study of the literature and framework**
- **Perform exploratory simulations**
- **Implement conversion of temperature maps in power units**

$$P = \int d\nu\, \mathcal{G}(\nu) \frac{c^2}{\nu^2} I_x(\nu) = \int d\nu\, \mathcal{G}(\nu) \frac{c^2}{\nu^2}\, b(\nu)\, T_{x,\mathrm{cmb}}(\nu) \longrightarrow P = \int d\nu\, \mathcal{G}(\nu) \frac{c^2}{\nu^2} I_x(\nu) = T_{x,\mathrm{cmb}}(\bar{\nu}) \int d\nu\, \mathcal{G}(\nu) \frac{c^2}{\nu^2}\, b(\nu)$$

$$B_\nu(T) = \frac{2h\nu^3}{c^2}\left(e^{\frac{h\nu}{kT}} - 1\right)^{-1} \qquad b(\nu) = \left.\frac{dB_\nu(T)}{dT}\right|_{T=T_{\mathrm{CMB}}}$$

TOD in power units can be used to study the detector response in order to improve the experimental design

Next Steps and Expected Results

- **Study the optimal way to implement crosstalk in the LiteBIRD sim**
- **Perform first simulations with crosstalk**

Next Steps and Expected Results

Thank you for your attention!